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Concrete Floors for Country Highway Bridges

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CONCRETE FLOORS FOR COUNTRY HIGHWAY BRIDGES

...BY...

Cleon Leslie Davis

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1904

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

CLEON LESLIE DAVIS

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Civil Engineering.

Ira O. Baker,

HEAD OF DEPARTMENT OF Civil Engineering

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Lumber suitable for floors for highway bridges is continually increasing in price and decreasing in quality, owing to the depletion of our forests; and this is likely to continue in the future at an accelerated rate. Such conditions seem to demand a substitute for lumber for bridge floors. Concrete appears to be the most promising material for this purpose. Although concrete has been employed considerably as flooring in large buildings, raised walks, city bridges, and railroad bridges, its use has not yet extended to country bridges. The reason is that the constructions which are suitable in the above cases are all too costly for the country highway bridge.

There are four somewhat distinct methods of using concrete for bridge floors.

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1. The concrete is supported by buckle-plates riveted to the joists. This method is quite common in city bridges.

2. The concrete is laid on a heavy and deeply corrugated sheet of steel, resting upon the joists. The corrugations decrease the amount of concrete required, since the floor is a succession of comparatively deep arches connected by shallower portions.

3. The floor may consist of reinforced concrete; that is, a wire net, or expanded metal, or independent wires or bars may be imbedded in the concrete so as to take the tension and thus develop the full compressive strength of the concrete. This form of construction is much used for floors of fire-proof buildings and has been used recently to a limited extent in city bridges.

4. The floor may consist of a slab of plain concrete resting either

upon or between the joists.

In the first and second method above the metal is usually capable of supporting nearly half of the load, and therefore the cost is too great for country bridges. There is a great variety of methods of reinforcing concrete, but all are from the nature of the case somewhat expensive, besides being protected by patents, and in addition require great skill in their construction. Therefore reinforced concrete is undesirable for highway bridges, if a better construction can be found. As far as the writer knows the slab of plain concrete has seldom if ever been used for this purpose, and it is the primary purpose of this thesis to investigate this form of concrete bridge floor.

The Experiments

As there are little or no data as to the strength of a slab of concrete when simply resting upon the top

of the joists or when placed between the joists. The writer determined to make some experiments to determine the strength of plain concrete when used for a ribbed floor. He concluded that it is better and more practical to construct the concrete in place between the joists than to rest the slabs upon the top of the joists. It is probable that the greatest stress that can come upon a concrete floor is that due to the concentrated pressure of a heavily loaded wheel. Therefore the writer determined to construct a section of concrete floor with the joists imbedded in the concrete, and submit it to a concentrated pressure gradually applied with a testing machine.

Two 6-inch 12¾ lb. steel I beams 5-feet long were placed 2 feet apart and were connected at their ends by riveting on two 6-inch

channels with their flanges turned out. A form 3 by 6 feet was then made by nailing 2 by 8 inch pieces together. A few sheets of newspaper were laid upon a smooth concrete floor, and the above wooden form placed thereon. A layer of concrete 1 inch thick was then placed in the forms, and on top of this the steel joists were laid. Concrete was then tamped between and around the joists until the wooden forms were filled. The relative positions of the I beams and the concrete are shown in Fig. 1 (page 10). The concrete was composed of A H Chicago Portland cement and clean coarse silica sand and crushed limestone ranging from ½- to 2 inches. The ingredients were measured loose and the proportions were as stated in Table 1. The concrete was allowed to stand in a steam-heated room for the length of time

slated in Joliet. The concrete was sprinkled daily for two or three days after mixing made. It was thought that this treatment approximated the conditions under which the concrete would be placed in actual practice.

When ready for testing, the wooden form was removed and the mass of concrete was placed upon the end of a testing machine. Each end of the concrete slab rested upon a 6-by 6-inch timber, the end of the T beam just reaching to the middle of the timber support. The load was applied to a small casting representing a portion of a tire 4 feet in diameter and a width of two inches. The load was applied midway between the joists and at the middle of their length See Fig. 1. The results of the tests are shown in Table 1.

TABLE I

Breaking Load of Concrete Bridge Floor under a Concentrated Wheel Load

Exp No.	Proportions of Concrete			Age of Concrete when Broken in days	Breaking Load in lbs.
	Cement	Sand	Stone		
1	1	3	6	23	20505
2	1	3	6	32	31600
3	1	4	8	7	11650
4	1	4	8	32	20010

The following facts were noticed during the progress of the experiments. In test No 1 there was no appreciable signs of approaching failure until the ultimate load was nearly reached, the first sign being fine cracks on the lower side having about the general position shown in Fig. II. Just preceding failure, cracks showed upon the upper surface similar to those on the lower face, except that the

apex of the corner was about 4 or 5 inches further from the load. In test No 2 the cracks in a general way were about as cited in the preceding test except that on both sides of the center one branch of the crack was larger than the other something as shown in Fig. 3. In No 3 the cracks were about the same as in test No 1, except the concrete was so green that the fire cut into it to a depth of about 3/4 of an inch. The form of the cracks in No 4 were about as in No 1 and 3. The concrete in specimens No. 3 and 4 was not wiped as thoroughly as that for No. 1 and 2, as was noted at the time of wiping, which probably accounts for the lower ultimate strength obtained in specimen No 4. Since the age in specimen No 3 was so much different from

the others, it is not possible to make any comparisons between this and the other results.

The tests show that the above arrangement of I beams and concrete will provide good and ample strength under ordinary conditions, particularly if the concrete is allowed to set a few days before being subjected to the maximum load. For in test No 3 the concrete failed under a concentrated load of 11,650 pounds; and as these 2 inches wide would seldom, if ever, carry a load of more than 1,500 lb., the factor of safety is 7.8 or practically 8, which is abundant, particularly as the concrete will gain considerable strength after it is a week old. Similarly the factor of safety in test No 2 for concrete 1 month old is 21, and for the leaner concrete of experiment No 4 is 13.

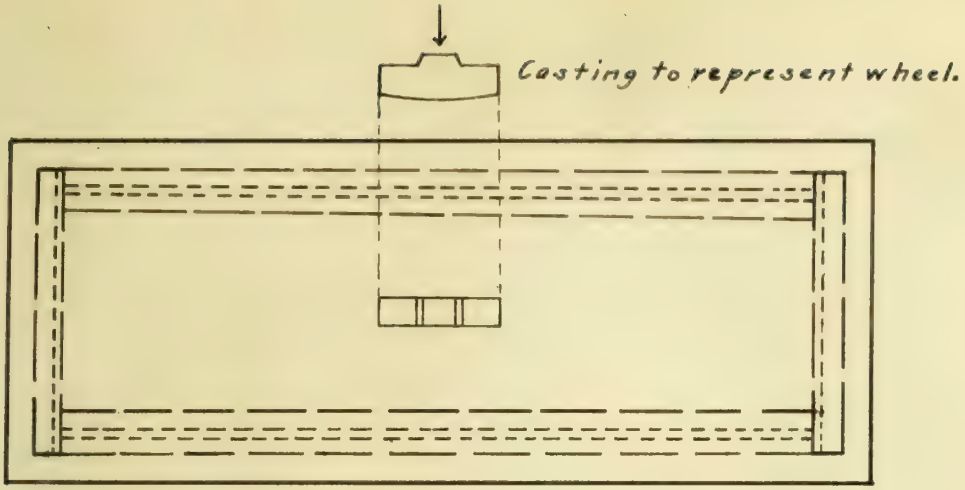

Fig. 1. Relative Position of the Load.

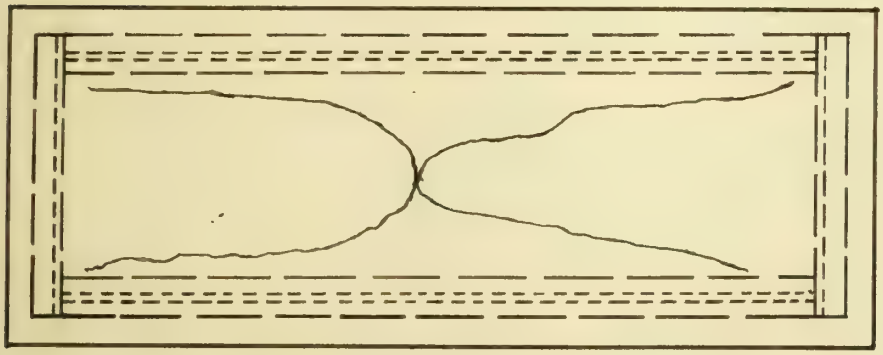

Fig. 2. Cracks on Lower Side - Test No. 1.

Fig. 3. Crack on Lower Side - Test No. 2.

The writer made an experiment in which the lower surface of the concrete was arched from beam to beam. An arched form 20 inches wide, 4 inches high, and of the same length as the joists, was laid upon the floor inside the 3- by 6-foot wooden form, and an inch of concrete was tamped around it, the steel framework was then laid in place as before, and more concrete was tamped about the I beams until the concrete reached an inch above the top of the joists. This slab of arched concrete was allowed to stand for 35 days, when it was tested in the same manner as the others. The pressure causing failure was 22,660 pounds. In this test there were no cracks extending from the center to the sides, the concrete simply being punched through. The surface of rupture made an angle

of about 45° with the line of pressure. These tests show that with arched concrete the depth under the load may be lessened without diminishing the strength of the section correspondingly, for the depth of concrete above the arch was lessened one half (from 8 to 4 inches) but the pressure causing failure was decreased only about one quarter — compare the above experiment with test No 2 in Table I. The arched section seems to be sufficiently strong; but it is doubtful whether it would be advisable in practice to make the thickness at the crown of the arch any less, since poor mixing or insufficient tamping might then cause unsafe conditions in the floor.

There are two advantages of arching the under side of the concrete: 1. The arched form decreases the amount of concrete, and therefore lessens the cost of the floor; and

2, the arched floor decreases the dead load on the budge, and thus for indirectly lessens the cost of the steel work. On the other hand, the arched form adds to the cost of construction. In actual practice a wooden form resting upon planks shored up against the lower side of the joists, could be used; but the cost of these arched forms and the trouble of placing and of removing them would add materially to the expense of the floor, particularly as it would probably be necessary to have enough such forms to permit the concreting of an entire panel at one time. With a view of finding a substitute for a wood form, the writer tried an arched form made of No 12 corrugated steel, the corrugations running perpindicular to the joists. This arched form rested upon the outer edge of the lower flange of the joists, and had a crown of

about 4 inches. The concrete was tamped over this form and between the joists. The prime object of this experiment was to determine whether the metal had sufficient stiffness to serve as a form; and the conclusion was that this thickness was sufficiently stiff for this purpose. With this form of arch the concrete floor would have a cross section about as shown in Fig. 4.

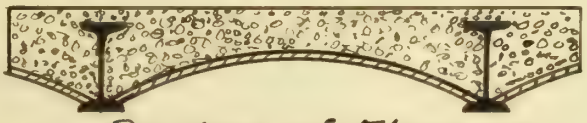

Fig 4. Section of Floor on Corrugated Steel Arches.

An experiment was also made on a section of concrete without the joists. A concrete slab 3-ft by 7½-inches by 6-feet was made and tested when 38 days old. The supports were 5-ft. apart and the load was applied in the center of the slab as before. The section failed under 6,980 lb. breaking square across.

A small beam 8 inches by 8 inches by 3 ft. was made from the same mixing of concrete, and was tested at the same age. Its supports were 32 inches apart and the pressure was applied in the middle of its length, but was not concentrated at one point as in the case of all the preceding tests. This beam broke under 4,060 lb. The modulus of rupture of the concrete was determined from the latter test, and then a comparison made in the slab test between the weight of the concentrated load causing failure and the weight that would have caused failure if the load had extended entirely across the middle of the slab.

Determination of modulus of rupture from the small beam.

Let S = Modulus of Rupture lb. per sq. in.

Then $S = \frac{Mc}{I}$ $M = \frac{Wl}{4} = \frac{4060 \times 32}{4} = 32,480$

$\frac{I}{c} = \frac{bd^2}{6} = 85.3$

$S = 392.5$

If the load on the slab had extended entirely across the middle the load required to cause failure would have been

$W = 7 S I = 8831$ lb. The concentrated load actually causing failure was 6,980 lb. The difference between the two is 8,831 - 6,980 = 1,851 lb., or the concentrated load is 79 per cent of the transversely distributed load. The explanation of the difference in the effect of the two above forms of loading is about as follows. If a load be applied uniformly along the line A-B Fig. 5, each unit of the load is sup-

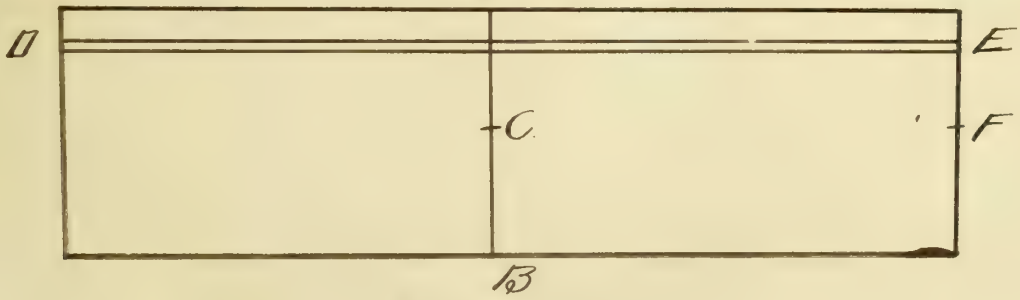

Fig 5.

ported by an elementary beam D-E having the same length and depth as the original beam; but if the load instead of being

distributed along it is concentrated at D, it be supported by a series of vertical laminae radiating from D and having the depth of the original beam and lengths varying from DB to DF. The longest of these beams is of course the weakest; and the shorter beams do not have a fixed support, and consequently can not carry their proportions of the load. Therefore when the load is applied at a point, the pressure is concentrated upon the weaker elementary sections, and the several elements fail in succession beginning at the weakest. It would be interesting to determine the exact relation between the load at a point and the maximum fibre stress; but the problem is a complicated one, and the present knowledge concerning the coefficient of elasticity of concrete and the modulus of rupture of a concrete beam

is so limited as to make an exact solution impossible.

Economics of the Concrete Floor

For an exhaustive investigation of this problem it would be necessary to determine (1) the most economic depth of joist, (2) the most advantageous distance between joists, and (3) the best depth of concrete.

1. Of course, the deeper the beam the more economical it is; but the strength of the floor under consideration depends upon the relative strength of the steel and the concrete; and the cost of the floor upon the relative cost of these two materials. Perhaps an approximate solution could be found for some particular case, but it is certain that a general solution depending upon assumed data would be of no practical value.

2. In the preceding experiments the distance between the joists

as fairly representative of good practice with "tank" floors; but it by no means follows that that spacing is the best for concrete floors. A panel length of concrete floor acts as a single mass, as long as a panel and as wide as the bridge, and it is practically impossible to determine either the lines of force between the concrete and the steel or the proportion of the load borne by each. This could be determined, if at all, only by a series of tests with a large number of deflectometers located at numerous points on the area deflected. These experiments to be of any considerable value should be conducted upon a full-sized panel length of bridge floor; but this is practically impossible, and therefore neither the mathematical nor the experimental determination of the most economic spacing is practicable.

Although it seems not practicable

to determine the most economical depth for the steel joists. It is reasonably certain that the concrete should be slightly deeper than the joists. There is some choice as to whether the concrete shall extend below or be flush with the bottom of the beam, or be arched and rest upon the upper surface of the lower flange. The only advantage of having the concrete below the lower side of the steel joists is that the metal is thereby protected from rust, which may be a matter of some moment with bridges having no other metal exposed to the weather; but as this would seldom occur, the protection of the lower surface of the lower flange of the joist is not a matter of much moment, since this part of the bridge can be easily painted at the same time as the other exposed portions. However the concrete should extend above and over the

I-beam for it extends only to the upper surface of the joists, the face of the steel beam will be exposed and will not afford a good footing for horses' feet, and besides the exposed edge of the concrete next to the beam is likely to be worn away and thus form a rut. The writer would suggest that the concrete should extend, say, an inch above the upper face of the steel joists. With this thickness there may be some trouble with the concrete's breaking off immediately above the steel I-beam; but only experience can determine the likelihood of this method of failure.

The economic value of a concrete bridge floor will depend upon the resistance of the upper surface to the impact and abrasion to hoofs and wheels. The durability of concrete in a bridge floor would be somewhat similar to that of a concrete pavement. Prof. F. H. Eno

'41 Professor of Municipal and Sanitary Engineering, Ohio State University, in Engineering News, January 7, 1904, gives an account of a recent examination of concrete pavements on two streets in Bellefontaine, Ohio, which had been in service ten years and which showed little or no signs of wear. Bellefontaine is a town of 6,650 inhabitants, and the concrete pavements were laid upon the two principal streets. In ten years the wear had been so slight that the imprint fits made for foot holds for horses could plainly be seen all over the surface. The Professor also stated that the concrete pavements in Grenoble, France, are said to have proved quite durable. Further the floors of country highway bridges are likely to become covered with 2 or 3 inches of earth, particularly on earth roads in an alluvial soil; and consequently concrete floors on country bridges are

likely to be more durable than concrete pavements on city streets. On the other hand the bridge is narrower than the pavement, and consequently there will be a greater tendency to form ruts; and therefore for this reason concrete bridge floors may not be as durable as concrete pavements.

The relative first cost of a concrete and a lumber floor is a matter of importance. The cost of a lumber floor will vary with the grade of lumber and with the locality; but with present prices a 2½-inch floor will cost 7½ or 8½ cts. per sq. ft. and a 3-inch floor about 9 to 10 cts. The cost of the concrete floor will vary considerably with the propinity of the sand and the broken stone, and also materially with the price of cement; but in most localities the concrete floor shown in Fig. 4 will cost from 10 to 12 cts per sq. ft. Therefore, in view of the greater durability of

the concrete, and considering only the cost of the floor itself, it is clear that the concrete is in the long run the most economical.

The weight of a concrete bridge-floor has an important effect upon the economics of the problem. With 6-inch I beam joists, and the concrete extending an inch above the steel, and the under face being arched as shown in Fig. 4, the weight of the floor is 60 lb. per sq. ft. The weight of a lumber floor varies from 11 to 14 lb. per sq. ft., say, 12 lb. for an average; therefore the concrete floor weighs 48 lb. per sq. ft. more than the lumber. To carry this extra dead load will require considerable extra metal in the other parts of the bridge. The expense of this extra metal would not be very serious in small bridges consisting of a single length of steel frame; but in trussed spans of any considerable length the

extra metal required in the trusses to carry the excess weight of the floor, would be a considerable part of the original cost of the bridge. At first glance, this would seem to prohibit the substitution of concrete for lumber in the floors of trussed bridges; but on the other hand, the railroads are substituting solid cast-steel floors for timber floors on trussed bridges. The reasons for the change in railroad bridges are somewhat similar to those for the substitution of concrete for lumber for floors of highway bridges. The writer regrets that the time available for this thesis does not warrant a careful consideration of this aspect of the case.

Conclusion

The author believes that he has shown that a slab of concrete an inch or two deeper than the ordinary steel joist has abundant strength for a country highway bridge.

He hopes that he has also shown the economic possibility of concrete for the floors short span truss bridges. Further, he believes that in the not remote future concrete may be used for the floors of short thru-truss span highway bridges.

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